# Internetworking and the Politics of Science: NSFNET in Internet History

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**This article presents an account of the process of development of the NSFNET and its significance for the emergence of the Internet of the 1990s. The fact that the development of the interconnected system of computer networks occurred within the realm of academic research is not incidental. The dynamics of the world of scientific research were intimately related to the shaping of the network and to the way in which it spread to other sectors of society. The construction of computer networks crossed the boundaries between science and society in order to build the scientific realm by transforming the world in which it is embedded.**

**Keywords** Internet, science and society, technology and society

The Internet is widely regarded as the first manifestation of the information and telecommunications infrastructure of the future or "the central organizing paradigm for information infrastructure" (Kahin, 1993, p. 143). One of its roots is the ARPANET of the Department of Defense, which began to operate in 1969. However, today's interconnected computer networks are also the result of networking activity that took place elsewhere and had significant impact on its characteristics. One important case was networking for supercomputer access, sponsored by the National Science Foundation (NSF) during the 1980s, leading to the NSFNET.

This article presents an account of the process by which the NSFNET was implemented. The fact that the development of the interconnected system of computer networks occurred within the realm of academic research is not incidental. Reports on the development of the Internet often fail to recognize the importance of the research community beyond the role of its designers or the later project leaders as carriers of a technology that contains all its possibilities within itself (Hart et al., 1992; Salus, 1995). However, the world of scientific research, with its institutions, policies, and disciplinary distinctions, shaped the network and the way it spread to other sectors of society. This result is in agreement with recent studies of science and technology that challenge the notion that technological development is controlled by a technical logic that is independent of the particular context in which it occurs (Bijker & Law, 1992; MacKenzie, 1990; Hughes, 1983; Latour, 1991; Callon, 1991).

The account presented here captures part of a process that has not yet ended and shows that there are multiple strands that become intertwined in a mesh that the computer networks exemplify beyond their functionality. Along the way, scientists redefined the way they do research, the networks were fashioned into new objects providing services, establishing relationships, and facilitating institutional coordination, and the world was transformed in the image of science. A phrase by Bruno Latour (1991, p. 116) would aptly summarize this process: "What we observe are groups of variable geometry entering into relationships with objects of variable geometry. All get transformed."[1]

The notion that information systems and computer networks are created and adopted only for their instrumental functionality has also been challenged by research showing that collective action by social computerization movements plays a decisive role (Iacono & Kling, 1996). These movements portray a vision of a new social order brought

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about by computers and communications systems. They recruit members for their organizations using the rhetoric of a technological utopia (Iacono & Kling, 1996, p. 93). Many participants in the process described in this article have advocated beliefs similar to those ascribed to the computerization movements. Occasionally, they would appeal to the idea of progress through computerization to build support for their initiatives. However, the process by which this key stage of the Internet developed illustrates the existence of such movements only indirectly. For the most part, networking was a means to other ends of the groups, organizations, and institutions involved in its development. It afforded groups of scientists, academic institutions, and government agencies that support research a higher degree of legitimacy for some of their activities by increasing the visibility of the interactions among members of the network. That was the case, as we shall see, for academic computer science departments that had not been part of ARPANET. It was also the case for federal agencies that argued that the network made new instances of research policy coordination unnecessary, given that it occurred at the program manager level over the network.

The case of computer networking, and the Internet in particular, can be added to the growing amount of evidence from recent studies of technology that the processes by which different technologies are created and become part of human social life are so different from each other that generalizations are very difficult. What different technologies become is closely tied to the processes of interpretation of what they actually do for us, not only when they are designed but also when they are adopted or diffused. Therefore, the full characterization of technologies depends on the particular social contexts and historical processes by which they became part of our social life. Their future is not determined by these contexts, but important constraints and some sense of their place among the rest of the objects in our lives will certainly have been established (Callon, 1991; Dosi, 1982).

The argument of this article is twofold. First, it makes the historical point that the NSFNET was a key link in the development of the Internet. It was not the only important contributor to the global system of interconnected networks, but it played a key role because in its development and implementation, several social interests, institutional programs, and technological developments that enabled the Internet converged for the first time. Second, it articulates the relation between the relevant social structures and computer network architectures. The latter are not mere technical instruments for providing well-defined services. They were developed in the process of institutionalizing scientific disciplines and satisfying interorganizational constraints in the federal government. As a result, they expressed and embodied, at least temporarily, the structures and positions of the groups, organizations, and institutions that participated.[2] The first section of this article shows how the situation of computer science as a discipline contributed to the networking process. There was nothing really extraordinary about the activities in computer science. For the most part, it can be explained with ordinary understandings of the dynamics of scientific disciplines, their "invisible colleges," the pursuit of resources for research and education, and their relations with the universities and private and public sources of funding. However, the fact that they created a computer network, the CSNET, to strengthen their social networks and legitimize computer science as a science had broad consequences.

The second section identifies and describes another phenomenon in academic circles in which the protagonists were physicists and chemists who used supercomputers for their research. A movement of computational scientists was sparked by the lack of access to supercomputers that academic researchers suffered from in the universities. The scheme for providing and sharing supercomputer resources among academic researchers across the nation included a network. The political clout of scientists in these fields and their ability to tie their work to concerns of national security and competitiveness brought national computer networks closer to the center of political attention. However, the feasibility of the computing environment they needed and its long-term sustainability required a broader constituency. Therefore, they led the creation of NSFNET but were not responsible for its ultimate shape.

The next two sections show in some detail how the constituency for NSFNET was extended and what effect it had on the architecture and implementation of the network. First, the two disciplinary processes in computer science and computational science came together in the first implementation of the NSFNET. Their similarities and differences had a decisive impact on the actual architecture of the network. Second, a key to the success of a general-purpose network, a feature of NSFNET decided in the previous stage, was that individual institutions, mainly university campuses, should build local networks and connect them to the backbone. A new set of relations and interests became part of NSFNET as a result, which provided most of the impetus for its explosive growth in the late 1980s.

## NETWORKING THE DISCIPLINE

Before a network for supercomputer access was actually considered in NSF, computer science researchers who were not part of the Defense Advanced Research Projects Agency (DARPA) projects sought support from NSF to create a network connecting computer science departments in the United States. The resulting network, CSNET (Computer Science Network), was more than a mere step on the way to today's Internet and illustrated the desire of people

outside DARPA to "get on the net." The project in itself was very successful, but its greater significance lies in the way in which the circumstances of the discipline of computer science played themselves out in the implementation of CSNET and the role its builders played in later developments in networking.

To researchers working under DARPA contracts, the ARPANET was more than a communications system. It was an experimental network and therefore also functioned as a laboratory in which experiments in computer communications were conducted. It had become a tangible domain of reality that computer scientists explored and created knowledge about. DARPA had a dominant position in supporting the development of computer science, and the ARPANET exemplified and reinforced it. The rest of the computer science community that did not work under defense-related contracts or grants was perceived to be weaker, a position reflected in its institutional standing. A high-ranking NSF official of the late 1970s described the situation as follows:

> The National Science Foundation always somehow—whether it be in chemistry, even physics, I would say certainly, above all, in mathematics and astronomy—really knew itself as being the primary force in the scientific establishment. In computer science there was no doubt about it they were playing second if not third fiddle to DARPA. You know, back in, 1979–1980 the computer research world was really divided into two sets—the DARPA schools, and what was then described as the outer darkness. (Charles Babbage Institute, 1990)

The context in which the ARPANET existed, therefore, reflected the situation of the discipline. Researchers with ARPANET access were able to interact among themselves continuously with ease and share facilities and programs as well as ideas. As a result, they became the core of the discipline and attained a degree of autonomy in their research that the discipline as a whole did not yet enjoy. In explaining how the idea of a computer science research network proposed to NSF had emerged, Douglas Comer stated that "researchers with ARPANET access tended to interact among themselves and ignore those without access" (Comer, 1983, p. 747). In a similar article published about the same time, other participants in the project said, "It was also clear that the ARPANET experiment had produced a split between the 'haves' of the ARPANET and the 'have-nots' of the rest of the computer science community. The participants at the meeting wanted to unify the computer research community and to improve research conditions for all its members" (Denning et al., 1983, p. 138). Therefore, there was more than the functionality of the network at stake for computer science researchers without access. They were also, to a certain extent, excluded from the exchanges taking place at the center of the "invisible college" of their discipline (Crane, 1973).

The idea to expand ARPANET to most computer science departments in the country was suggested at the very beginning by Robert Kahn of DARPA, one of the main architects of the ARPANET and an ardent promoter of the extension of computer networking. However, the expansion did not occur mainly because most computer science departments could not afford the expense of the installation and connection charges, nor could NSF sponsor all of them. Therefore, the group of computer scientists led by Larry Landweber, chairman of the computer science department at the University of Wisconsin, with strong support by Peter Denning, then at Purdue University, and Anthony Hearn of the University of Utah, went ahead with a proposal that would attempt to develop ARPANET functionality using X.25 common carrier data services.

Apart from the technical specifications, the researchers and NSF staff had several special concerns. First, an adequate management scheme for such a multi-institutional project should be found. Second, an access policy had to be adopted that was compatible both with the needs of the computer science community and with the openness required by the objective of sharing expensive resources that the foundation was pursuing. Finally, the network could not count indefinitely on NSF grant funds and therefore should become self-sustaining after a maximum period of 5 years (Comer, 1983, p. 748).

The project was received with skepticism, mainly because of the management issue. To begin with, the orientation of the foundation toward basic research, which based its granting policies on peer review along disciplinary lines, put this kind of project outside its natural management competency. Once reviewers recommend a proposal for funding based on its academic merit as a contribution to the field, the foundation usually does not manage the projects directly. At the same time, basic research projects are generally conducted by small teams of researchers within the boundaries of an academic institution or research laboratory. The interinstitutional and administrative problems involved in setting up infrastructure projects, though not new to NSF, created special problems. This contrasts with the Department of Defense (DOD), Department of Energy (DOE), and National Aeronautics and Space Administration (NASA) as "mission" agencies that have an organizational structure with a highly directive management style. Even when contracts are granted to university research teams or private contractors, program managers in these agencies generally oversee the projects more closely to ensure that the mission is fulfilled.

The proposal received poor reviews and was not funded at this stage. The reviewers objected that it was not a research project to advance knowledge in the field and that the principal investigators were not experienced in the implementation of networks or in the management of large development projects. In spite of the rejection, the

process continued. The situation of the discipline of computer science was being considered more generally within NSF. A group of university researchers had organized a workshop and produced a report entitled "Rejuvenating Experimental Computer Science," commonly known as the Feldman report. The Office of Science and Technology Policy (OSTP) was working on a national policy for the area of computing, though it focused on DARPA as its main implementor. The measures discussed to overcome the crisis in American experimental computer science included the creation of a computer network for research.

These circumstances allowed the CSNET proposal process to continue despite the initial rejection. NSF computer science staff, especially with the leadership of Kent Curtis, head of the Computer Science Section of NSF's Division of Mathematics and Computer Science, suggested that the proposal be rewritten as a study project in order to gather the information needed to address the concerns raised by the reviewers. With respect to the management problem, NSF appointed a member of the Division of Chemistry, which was also under the Directorate of Mathematical and Physical Sciences, C. William Kern, to assist in the proposal submission process and then manage the project for NSF once approved by the National Science Board. This was a rather unusual procedure for the foundation and an indication of the lack of clout computer science had as a discipline vis-à-vis the other disciplines in the directorate.

The study proposal was funded and plans for the new network proposal were made at several meetings held during the year in 1980. Robert Kahn appointed Vinton Cerf, another key architect of the TCP/IP protocols, to provide technical support and strengthen DARPA collaboration with the NSF networking program. The idea of implementing CSNET as a logical network was proposed during this study. In order to provide access to as many computer science departments as possible, the network would be accessible in several ways. In decreasing order of expense these were: directly from the ARPANET; using public data networks; and via telephone lines to a central server. The proposal included the development of software allowing transparent connectivity between sites on ARPANET and others using public data networks.

The second proposal was funded. Even though critics still voiced the same objections, enough peer approval in the discipline had been gained and the implementation of CSNET began. With that, the discipline acquired one of the most important means that helped computer science achieve full status as a legitimate field of basic science.

## SUPERCOMPUTERS BRING NETWORKING INTO BIG POLITICS

Developments in the natural sciences that would later be important for the networking initiative were taking place independently of what was occurring in computer science. During the 1970s, the use of supercomputers in certain areas of physics and chemistry increased significantly especially among scientists with grants or contracts from DOE. Actually, DOE worked closely with the developers of these special high-performance machines in order to ensure that they would have the highest level of computing power available (MacKenzie, 1991). The use of these machines allowed researchers to calculate numerical solutions to the differential equations of physics and chemistry under very complex and realistic conditions. However, during the same period, no university in the United States was able to purchase any of these machines. As a result of the lack of these tools in the universities, the disciplines had suffered a major split (Smarr, 1995). Researchers trained in the use of such machines had developed insights and a research methodology using simulations that were almost unknown to academic researchers who had little or no exposure to such computing power. It also created a generational problem because most of the latter were older researchers who had either graduated before the supercomputers became available or had always worked in the academic environment that had no access to them. Even in the 1980s, many scientists still considered numerical approaches to problems to be a crude alternative and a sign of lack of the intellectual ability needed to find proper analytic solutions (Smarr, 1995).

The situation that developed had some of the same institutional characteristics existing in computer science. Researchers with access to supercomputers, almost exclusively available to those who worked in relation to DOE, were moving farther and farther away from academic researchers without such access. The line was drawn between researchers related to a major research-supporting federal agency, DOE, and academic researchers in universities, just as DARPA led the way in computer science.

A group of scientists who used supercomputers for their research, but who had done so with great difficulty given the limitations on access to DOE computers, began discussions about these problems. A few universities in Europe and Japan had installed supercomputers and made them available to their scientists and, on several occasions, American scientists working in collaboration with them had succeeded in obtaining NSF grants to travel abroad in order to use American-made supercomputers. In 1981, a panel chaired by William Press, which included prominent computational scientists such as Kenneth Wilson and Larry Smarr, published a report for NSF that recommended the installation of widely accessible supercomputer centers (Press, 1981). The report was not well received in the physics community as represented in the NSF Physics Advisory Committee, mainly because the facilities would be very expensive, almost on the order of magnitude of a

particle accelerator, which many would have preferred to a supercomputer center. Most academic researchers did not believe supercomputers were critical to the advancement of knowledge in the field. There had been significant growth in the previous few years in the local availability of minicomputers at university laboratories. This process had gradually made researchers independent from the campus computer center and the latter largely irrelevant to science. Therefore, without the guarantee of a significant infusion of new funding, the recommendation threatened to divert resources away from grants for research projects and local equipment and a return to a sort of operation resembling the shared computer center.

The OSTP was paying close attention to the issue of the health of the American computer and microelectronics industry and its relation to research in universities and the government sector in the face of recent gains by Japan in the share of certain critical markets. Japan announced in 1981 that it would launch a national program in computing with an artificial intelligence component, the "fifth-generation program," and a supercomputer component.

In 1983, several Japanese companies appeared to be ready to deliver supercomputers of comparable performance to the top American machine at the time, the CRAY 1. The circles of science and technology policy were very busy discussing the changes that were necessary in the relationship between government, industry, and academia to meet the new challenge. Japanese success in targeting markets and dominating them seemed to require rethinking basic assumptions of the economics of innovation in competitive markets. The undisputed preeminence of the United States in the area of microelectronics and computing was threatened, and policies to revert the perceived trends were being discussed.

In this context, the scientists who were demanding increased availability of supercomputers for research were able to link their needs with the overall competitiveness and security concern that loss of leadership in the field of advanced computing had created in top policy circles. The strategy they pursued was to broaden the scope of their movement outside of the discipline of physics. As a result, another study was conducted in 1982 under NSF and DOD sponsorship, with DOE and NASA collaboration, by a multidisciplinary panel leading to the influential "Lax report," named after the mathematician Peter Lax, who chaired the panel (Lax, 1982). NSF followed up with another workshop and report to articulate recommendations for the foundation's contribution in the area (Bardon et al., 1983). The situation was presented as a "new Sputnik" that required immediate concerted action and succeeded in attracting the attention of Congress, which held two hearings on the matter in 1983 (U.S. Congress. House, 1983a, 1983b).

The proposal at this stage addressed the needs for high-performance computing in all fields of science and was designed to stimulate the demand for supercomputers, therefore contributing to the improvement of the country's competitive position without implementing a directive industrial policy. The size of the program was significantly larger: ten centers were now proposed to be connected to a wideband telecommunications network and the budget climbed to the order of $100 million per year.

When NSF actually developed the plan for the next year, with the creation of the Office of Advanced Scientific Computing (OASC), and negotiated with the Office of Management and Budget (OMB) the amounts to be appropriated, it was authorized to request only $20 million. The members of Congress had actually been very receptive to the scientists' presentation and doubled the amount to $40 million for FY85.

The policy discussions and administrative instances just described might seem at first sight to be incidental and almost irrelevant to the development of networking, as some have argued (e.g., Salus, 1995; Hart et al., 1992), except for the historical detail that this was the vehicle that brought ARPANET networking technology into the outer world. However, there are several reasons why it was constitutive of the networking environment that resulted. To begin with, there was no specific role assigned to the ARPANET itself in the conception and discussion of the plan at this stage. The idea of a computing environment for academic research came to the attention of lawmakers for the first time. Several became enthusiastic promoters of new telecommunications and information infrastructure in the following years, prominent among them then Representative Albert Gore. This was also the first multidisciplinary effort with a national networking component that was put into a program that had good chances of implementation. The network itself went a long way in making those ties between disciplines visible. The dual meaning of networking, connecting people as well as computers, was invoked very successfully in several contexts at later stages of the development of networks.

Without the connection to the competitiveness and security issues, it is very doubtful that networking would have become such a prominent component of government initiatives in the following years. At the same time, computer science as a discipline did not have the political clout to create the kind of movement required to link its research to central issues of the national interest, such as security and competitiveness, even when it had the arguments. Actually, as we discuss later, the interactions between computer scientists and computational physicists and chemists once the program was launched were integral to the networking development process. Finally, without a direct "cutting-edge" science demand it was almost impossible to justify the creation of a broadband network for

general-purpose communication, even if it were limited to scientists, because it would have been in direct competition with the common carriers, a point that was actually made repeatedly while plans were discussed.

## THE CONVERGENCE OF COMPUTER AND COMPUTATIONAL SCIENCE: NSFNET

An advanced scientific computing program was launched in 1984 with the creation of the OASC. However, it appears that the bold move by NSF that this report recommended was not viewed by all as a wise one, given the complicated relations between disciplines in academic research and between agencies in federal research and development (R&D). To begin with, the size itself of the project was an obstacle and it was not a research program to expand the "frontiers of knowledge." Given the charter of the foundation, the level of funding for these activities could not be expected to exceed a certain fraction of its total budget. There was also concern that it played right into the dark side of interagency competition and would end up hindering the overall process. The program was interpreted as a move by NSF to enlarge its own area of influence at the expense of other agencies, especially DOE, in the supercomputer arena. The opportunities for collaboration and coordination with other agencies were threatened from the outset.

The multidisciplinary character of the program also cut across agency lines in the federal system of research and development. Supercomputers and research in physics and chemistry using supercomputers were mainly in the domain of DOE, which actually owned most of the machines in existence around 1980. Networking was plainly in DARPA's field. NSF, for its part, was trying to facilitate the process of improving the availability of computer resources for researchers in universities that were not working under agency contracts. The expectation of legislators on the oversight committees was that the large federal initiative that was now envisioned should not lead to redundant programs in the agencies. Rather, it should be an opportunity to begin to work toward the new partnership between government, industry, and university that would ensure the country's preeminence in high-performance computing and its applications. Therefore, the interest of the legislators focused on the issue of coordination among the agencies and groups that participated in it. The OSTP gave the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) this responsibility, and new panels were created to monitor the supercomputing and access issues. However, no unified federal program was launched at this time.

At the time of the creation of OASC at NSF in 1984, CSNET was into its third year of NSF funding and its development was going according to plan. The skepticism that had made the proposal process quite lengthy and painful was dissipating in the face of the success of CSNET in achieving its stated objectives. The leaders of the project were in a good position to bring their experience and newly acquired reputation as network builders and managers to bear on the supercomputer access problem and propose the next level in networking. They presented an implementation plan based on the CSNET model called SCIENCENET, which would be carried out in two phases (Adrion et al., 1984).

The idea was to build on existing academic/research networks to provide access to supercomputer services at the earliest possible date to enable users of ARPANET, BITNET, CSNET, MAILNET, and MFENET as well as researchers using public data networks to utilize supercomputers located at the national centers. A wideband network would be developed in a second phase based on satellite links.

The standard protocol of the network would be TCP/IP and, given that it attempted to enable users from all the specialized networks to access the supercomputer centers, gateways and protocol conversions would be needed for networks such as BITNET and MFENET, for example. Clearly, it was an extension of the policy with which CSNET's X25NET was implemented and would indirectly lead to convergence of networks in the academic sector toward ARPANET technology.

The fact that there was no existing wideband network carrying the kind and amount of traffic SCIENCENET was expected to would turn the second phase into the implementation of an experimental testbed (Adrion et al., 1984, p. 10). However, an experimental network was not an obvious solution to the supercomputer access problem of physicists and chemists. At this time, the computer science network researchers had virtually no influence on developments. The people who were powerful were the physicists, and most of them saw no need for a networking project. Rather, they expected direct leased lines from their laboratories to the supercomputer centers. As a result, the SCIENCENET proposal as such was not implemented (Landweber, 1995).

The first decision on networking by the OASC, actually, was to request a massive expansion of the ARPANET. Robert Kahn had encouraged NSF–DARPA collaboration and was instrumental in the development of CSNET by opening ARPANET to outside traffic and appointing Vinton Cerf to provide technical support. The OASC consulted with Kahn, and he was supportive of the idea of adding the supercomputer centers as nodes on the ARPANET. A contract was drawn up and approved by the National Science Board of NSF and submitted to DARPA for ratification.

After some time no response was forthcoming. Kahn had left DARPA in the meantime, the split of ARPANET and MILNET had recently been completed, and the

decision on this matter was actually out of the hands of DARPA. The Defense Communications Agency (DCA), in charge of the management of the network, was overloaded with the demands from DOD sites and could not address the needs of NSF (Kahn, 1995). At NSF they had hoped they would not have to take charge of building a network. It was already early 1985, the supercomputer center awards were ready to be announced, but no advances were made on networking for remote access (Connolly, 1995).

In January 1985, Dennis Jennings, an Irish network specialist who had participated in setting up a network for higher education in Ireland and had been involved in the creation of the European version of BITNET, EARN (European Academic Research Network), was hired by NSF to direct networking in the OASC. He had been invited to participate in SCIENCENET meetings at NSF and introduced to the OASC director, John Connolly, by Landweber (Landweber, 1995). He then was charged with the task of leading NSF in building a national network for supercomputer access. When he arrived at NSF, the agreement for a substantive expansion of the ARPANET had failed to yield results and there was no definite idea on how broad access would be provided. Jennings was given the responsibility of finding a way to achieve that objective and had to start basically with a clean slate (Jennings, 1995).

The advisory committee that NSF created to assist Jennings included several of the people responsible for CSNET, such as Lawrence Landweber and David Farber, plus some additional people of the networking community in other federal agencies and private industry. Three key decisions were made by Dennis Jennings at this time and endorsed by this committee. First, NSF would implement a general-purpose network rather than a specialized one for supercomputer access. Second, the architecture of the network would involve a hierarchy with a high-speed backbone entirely supported and run by NSF, mid-level networks belonging to university consortia, state–university partnerships, or other specialized groups, and local area campus networks in the universities. Third, it would adopt TCP/IP as the standard protocol for the entire system (Jennings, 1995).

Two contextual factors were part of the considerations for choosing this strategy. First, the network would have to be built with limited funds that were obviously insufficient to finance the implementation of a general purpose network reaching the entire academic sector. Therefore, by funding only the backbone that provided the transport medium to span the system and providing seed money for networks at the regional and local level, it encouraged universities, state governments, and private corporations to invest in building the other two tiers. Second, the divestiture of AT&T was made effective during 1984 and the telecommunications market was beginning to take shape under the new rules. Jennings explicitly considered that the hierarchical model would work in a fashion analogous to the divestiture arrangement with the long distance companies interconnecting the Regional Bell Operating Companies (RBOCs; Jennings, 1995). It turned out to be not merely a conceptual analogy; it also matched the economic dynamics of the new telecommunications environment. In particular, by aligning with the regionalization of telecommunications, it was expected to encourage the RBOCs to enter partnerships with states and universities in their regions and participate in building the second tier of the hierarchical model, which actually did happen in several mid-level network implementations a few years later. The idea of a hierarchical network had been invariably present in discussions of networking for research and education at least since the mid-1960s. More than a decade before internetworking protocols were designed, the idea of a "network of networks" was proposed in the early Interuniversity Communications Council (EDUCOM) workshops to tie together information resources of various kinds being developed by various sectors of the academic world (Brown et al., 1967).

The actual structure of the NSFNET was therefore partially a result of two processes of institutional isomorphism (DiMaggio & Powell, 1983). On the one hand, it mimicked the structure of the telecommunications sector to map itself onto the way of doing things in, and becoming part of, the outer world. On the other, it also resulted from a normative process by which it sought to achieve legitimacy in the eyes of its various constituencies (professions, government agencies, business), which had to invest in the system to make it grow.

Jennings's proposal of a general-purpose network based on TCP/IP had to win the approval of the researchers whose main interest was supercomputer access. After all, it was very similar to the SCIENCENET proposal that had not prospered before. The argument for a general-purpose network was mainly that it had a better chance than a specialized one of being sustainable in the long term. Once a general-purpose network was operational it could serve the diversity of information access, processing, and exchange of the entire academic community, including access to supercomputers. By serving a larger constituency, it would have many more sources of support when grant money ran out. In the short term, scientists who had their applications ready and waiting for supercomputer time would not be as well served because they would not immediately have the effective high-speed connections that were possible with direct-leased lines.

A general-purpose network would need a standard set of protocols to guarantee compatibility among all its parts. Dennis Jennings and the OASC decided that NSF would award grants in networking only to proposals that adopted or developed their network components with TCP/IP as their data communications protocol. By then, deliberations

over data communications standards at the International Standards Organization (ISO) had already been going on for several years and the ISO/OSI standards were the result in the international arena. However, there was no protocol implementation that included the entire set of specifications contained in the standards. Vendors of networking products, such as IBM and DEC, were actively involved in the process, trying to get their products adopted as the OSI standards. Digital's DECNET was popular among physicists and was proposed by some of them as the NSFNET standard.

However, the overall picture was not reassuring to those whose priority was to have access to supercomputers. After all, TCP/IP was still in development and there were not many actual software implementations of the protocols. The ones that were available were computer science implementations and not industrially robust implementations (Jennings, 1995). Further, there was no actual experience with supercomputers using TCP/IP. On the one hand, the network would be working in a high-speed and high-volume situation and high reliability was expected. The ARPANET had not actually been tested under such conditions, a concern that had already been voiced when its expansion was being considered. On the other hand, there was no implementation for interactive access to supercomputers (Karin, 1995). For the TCP/IP experts the lack of such experience was not a great obstacle and the solutions they envisioned were at hand. They believed there was no technical reason why TCP/IP could not be implemented to operate successfully under such conditions.

The basic problem was that no matter how sound the project might have been from a technical point of view, it was still basically an experiment that would not serve the immediate interests of the users who were actually in control of the program. Access to the supercomputer centers had to be provided to physicists and chemists distributed throughout the country without delay. A general-purpose network with the potential to develop all sorts of applications, none of which existed yet, based on protocols for the most part unknown to people outside computer science and the ARPANET, would not satisfy that need in the short term. However, TCP/IP and the networking possibilities that could be developed with it were the consensus of the computer science discipline. Essentially, the interests of the disciplines were still in opposition and, given that the networking project was part of a larger initiative for the physicists, the internal disciplinary consensus in computer science on a topic that belonged in their field was not sufficient to drive the policy.

In the meantime, the supercomputer centers were allowed to operate networks with nonstandard protocols. For example, the San Diego Supercomputer Center (SDSC) implemented a clone of the MFENET, the network based on protocols derived from an early version of DECNET that provided access to the magnetic fusion energy computer center at DOE's Lawrence Livermore Laboratory. This was actually the first national network providing supercomputer access to academic researchers and served the community for several years until NSFNET was operating satisfactorily (Karin, 1995).

Jennings's proposal was finally approved by representatives of all parties involved after intense negotiations. Several participants recall a catalytic meeting held in mid-1985 at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Jennings presented his plan, based on a general-purpose hierarchy with TCP/IP, to supercomputer center directors, NSF staff, and some prominent members of the research community. The objections were raised and after a day of discussion the group agreed to support the proposal (Jennings, 1995; Karin, 1995; Smarr, 1995).

Several factors made this agreement possible. To begin with, it was in nobody's interest to continue delaying the beginning of a more general supercomputer access solution. The failure of the ARPANET expansion and the cold reception of the SCIENCENET proposal had already taken more than a year and no concrete action was being taken. At the same time, the movement for supercomputer access had already included other disciplines besides physics in order to gather enough support for installing several national centers. The idea of serving a broader constituency was already part of the agenda of the leaders of the supercomputer movement. However, the size of the program now required that they succeed in that regard because it had little likelihood of surviving in the long term otherwise. Therefore, some prominent members of the physicists' group were strong supporters of a general-purpose network. The problem was finding a way to implement it without paying the price in time and resources for ongoing research activities. In the words of one of the network builders, "Infrastructure is every researcher's third choice. They want, first of all, research students. Then they want funding for equipment for the research, and everything else comes third."

The computational scientists in physics and chemistry were not yet in the mainstream of their disciplines outside the mission agencies. They were concerned with more than the funding for supercomputers. There was still the need to establish the legitimacy of their way of doing science and then to press on to show that they were at the forefront of profound changes in the very nature of the scientific enterprise. They argued that a "third way" of doing science should be added to the two main practices of science, theory and experiment. It was constituted by the realistic simulations made possible by high-performance computers. With the "third way" also came a new aesthetic of science that superseded the priority of elegant and simple

analytic solutions. Instead, scientists' intuitions should be educated to find patterns that can be made explicit only by visualizing an array of numerical solutions to more complex problems. In light of this, science in most disciplines had to be carried out in a new environment that also linked it to productive processes of the economy. It functioned "as a single organism in which the personal computer, the network and the supercomputer is one entity and that entity is what is used by the scientific community and by industry to solve problems and develop productivity" (U.S. Congress. House, 1985, p. 87). This rhetorical strategy was the clearest case in which the supercomputer movement framed its goals in a form of technological utopianism (Iacono & Kling, 1996). The new computational environment would enable a new and superior order of scientific achievement.

Even though the use of supercomputers grew steadily, as we already mentioned, arguments against its being a new direction in which research in the natural sciences was going were not uncommon until very recently (Smarr, 1995). Therefore, the computational scientists themselves were trying to reach out to people inside and outside their own disciplines in order to encourage approaches to problems using supercomputers. Kenneth Wilson, who won the Nobel prize in 1982 for research involving algorithmic approaches to elementary particle theory (Wilson, 1985, p. 10), coined the phrase "grand challenges" to refer to a set of problems in various disciplines that could be solved only with supercomputers (U.S. Congress. OTA, 1989, p. 15; U.S. Executive. OSTP, 1991). This definition of the direction in which science ought to go proved to be very successful and gave the conceptual basis to the High Performance Computing and Communications Program several years later.

The computer science community had to be included in this process if it was to achieve sustainable results. Given that TCP/IP was the computer science community consensus on state-of-the-art computer networking, it would have been almost impossible for them to be involved significantly in the networking initiative if a decision against it had been made. Therefore, from the point of view of those leading the supercomputer initiative, if they wanted to recruit academic computer scientists for their cause, they would have to let those computer scientists decide this issue. In the language of actor-network theory, TCP/IP and computer science became an obligatory passage point for academic computer networking.

## BRINGING THE CAMPUS BACK IN: THE ROLE OF THE ECONOMICS OF ACADEMIC COMPUTING

The networking architecture and policy adopted by NSF in 1985 under the direction of Dennis Jennings brought a large group of organizations into the networking program in a relatively short time. Networks in other federal agencies, such as ARPANET, SPAN, and MFENET, and in the academic world, such as CSNET and BITNET, and those associated with the supercomputer center consortia became mid-level networks of an overall interconnected system. In terms of creating a broad base of support that could lead to a new computing environment for science, the formation of regional organizations to connect the campuses of most universities was a critical development. As soon as the networking policy was announced, groups of universities began to organize in order to facilitate the connection in a region.

The scientists who led the supercomputer access movement were also heavily involved in encouraging their own universities to install campus networks and connect to the national backbone. For example, one of the earliest groups of institutions to develop a regional network was in the state of New York as a result of NSF's award of a grant to Cornell for one of the supercomputer centers under the direction of Kenneth Wilson. From the very beginning, Cornell developed a partnership with the state government and several private corporations that had major research facilities in the state, such as IBM, Eastman-Kodak, Corning Glass, General Electric, and the RBOC NYTEL (Mandelbaum & Mandelbaum, 1992, p. 62).

Several of these universities were members of the Associated Universities, Inc. (AUI), which operated the Brookhaven National Laboratory and National Radio Astronomy Observatory. In early 1982, they had begun discussions about the lack of access to high-performance computing on their campuses and formed the Consortium of Universities Concerned About Campus Computing (CU4C). In this process, the experience with acquisition and management of large-scale experimental equipment such as accelerators and telescopes was applied to the installation of a supercomputer center. The difference, of course, was that supercomputers were not instruments for researchers in a single discipline. Therefore, in CU4C they brought together high-level administrators of member universities responsible for campus computing to design a common strategy in large-scale computing (U.S. Congress. House, 1983a, p. 354).

In 1985, this particular group was ready to take advantage of the NSF policy and created NYSERNET (New York State Education and Research Network). A similar development took place with the consortium of southeastern universities, SURA (Southeastern Universities Research Association), which operated the Continuous Electron Beam Accelerator Facility in Newport News, Virginia, that built the SURANET. Both consortia had operating mid-level networks connected to NSFNET by mid-1987. Other organizations with a variety of arrangements in terms of partnerships, cost sharing, and user support were formed after 1985, such as BARRNET, WESTNET,

MIDNET, NORTHWESTNET, and SESQUINET, among others.

These organizations supporting the mid-level networks were the context of several important developments. They established the key link with the university campuses. That is where the researchers, the main users of the supercomputers and other facilities made accessible remotely, were located. The main constituencies for everybody involved in one part or another of the new computing environment for research activities had to be reached on the campuses. Therefore, the success of the combined movement of computer scientists and computational scientists depended on getting most campuses to install local area networks and connect them to the national backbone (Jennings et al., 1986; Landweber et al., 1986).

The search for strategies in university computing has been a very much discussed and rather difficult issue. In the context of EDUCOM, the idea of a national network for research and education as a way of sharing information and computer resources had been ongoing for two decades by the time the implementation of NSFNET began. One of the outcomes of this process was the implementation of EDUNET in 1978 (Emery, 1979). But the results of the discussions among university administrators over those years fell far short of the expectations that were expressed when the possibilities of information technology for transforming the environment of research and instruction in the universities were presented (Brown et al., 1967; Greenberger et al., 1974). Apparently, it was very difficult to get the level of interuniversity cooperation necessary for the greater vision of the national network to be implemented (Greenberger et al., 1974, pp. xi, 21, 22). As a result, major inefficiencies in the distribution of computer resources continued to be encouraged by existing government and university policies. Interestingly, in the early 1970s it was suggested that a free market for academic computing resources should be implemented in order to correct the situation (Greenberger et al., 1974, pp. 195, 205, 238).

Besides the distribution of computer resources among universities, the other dimension of the dilemma of campus computing was the relation between the university computing center and the departments. During the 1970s, engineering, natural sciences, and computer science departments had purchased minicomputers that were dedicated to the research projects of faculty and graduate students. For the most part, these purchases were made with no overall institutional policy for computer resource acquisition. This process, often referred to somewhat euphemistically as the "decentralization" of campus computing, created the suspicion that most of those computing resources were seriously underused.

In the early 1980s, several major universities were revising their telecommunications and computing policies, partly to take advantage of the new regulatory environment that would be created by the deregulation of the telephone service. They were attempting to integrate voice and data communications in new campus networks owned by the university. Even though, for the most part, it was not possible to implement such networks at the time, it led to significant institutional innovation and the creation of high-level administrative positions in charge of information and telecommunication policies of the university, and plans for new campus networks were prepared and discussed (Arms, 1988; McCredie, 1983).

The NSFNET, with the hierarchical architecture and the choice of TCP/IP as the standard protocols, provided a concrete channel to unify these otherwise dispersed efforts. It did so, not only by offering one set of rules to play by in the administrative decisions to implement campus infrastructure. It also provided both incentive and pressure along the two dimensions of academic life that tend to work at cross-purposes when dealing with shared resources: the university dimension and the academic discipline dimension. Besides the deliberations and planning going on at the university administration level mentioned already, a few computational scientists at each of the most important research universities demanded the installation of local networks and the connection to the national network. These were, for the most part, important faculty members with large grants who had influence on campus. They had the kind of clout that computer science departments in general, excluding the DARPA schools, did not have (Smarr, 1995).

It had long been observed that one obstacle to efficient distribution of resources in higher education was that needs tend to be identified and distributed along discipline lines. Therefore, the incentives for the participation of researchers in meeting these needs, such as some of the networking efforts and information resource developments, responded to their discipline rather than their university affiliation. On the other hand, resources were distributed along university lines. Therefore, internally, departments representing the disciplines competed for the resources of the universities, making the balancing act between conflicting goals, timing, and needs inside each institution very difficult. Externally, universities competed to recruit top faculty in each discipline. In this competition the internal availability of resources for research is a major argument and works against interuniversity cooperation.

This is also a problem for multidisciplinary research funding organizations such as NSF. Even though its charter does include the provision of support for higher education and research infrastructure, projects that cut across disciplinary lines challenge a fundamental value of the scientific community: peer review as the ultimate quality-control mechanism to assign research resources. The Bardon-Curtis report of 1983, which recommended the installation of supercomputer centers and a network for access, specifically addresses this issue. It suggests that a

computer infrastructure for science, with supercomputers, networks, and personal workstations, is analogous to an "interstate highway system which supplies the infrastructure necessary for transportation and communication but leaves it up to the dynamics of the free market to work out which cities will prosper" (U.S. Congress. House, 1983b, p. 331). It meant that the interdisciplinary nature of the large computing program would not interfere with peer review but rather would enhance the general possibilities of research and its evaluation for the purposes of resource distribution just as the highway system does with trade in a free market. That it actually would work out this way was predicated on new funding in order not to redirect any part of the existing budget away from the grant awards administered by peer review within each discipline. When the program received support below the proposal's projection, the multidisciplinary coalition became strained and, for example, networking and supercomputers were seen in competition with each other (U.S. Executive. OSTP, 1987, pp. 120, 149).

The campus connection introduced a new element in the long discussion about higher-education computing. EDUCOM tied its efforts to facilitate improvements in this area to the new networking developments under the NSFNET umbrella. Its Networking and Telecommunications Task Force (NTTF) was responsible for calling attention to the educational aspect of networking. Therefore, when the High Performance Computing and Communications program was proposed, as a result of then-Senator Albert Gore's interest in the next stage in telecommunications and information infrastructure, the networking component was changed from National Research Network to National Research and Education Network (NREN). In other words, this new constituency appropriated the NSFNET developments and tied their long-standing concerns in the area of university information technology to the researchers' networking initiative.

Another critical link that was nurtured in the context of the mid-level networks was the relationship with industry and state governments. The telecommunications industry was going through the difficult process of restructuring as a result of the regulatory changes and had not participated significantly in the national-level process described earlier. The industry had representatives on all the relevant advisory committees and monitored the process as it unfolded. The development of the industry perspective during this period deserves greater attention than we can grant it in the space of this article. However, we can say that the telecommunication companies did not take an active role for several reasons: They did not believe the scientific community was a large enough market; they lacked the expertise in the novel aspects of computer networking; and they were concerned mainly with making sure that whatever was implemented did not constitute unfair competition with the common carriers. Only in 1988, when NSF contracted with Merit, Inc., of Michigan, IBM, and MCI to upgrade and manage the backbone, did this participation become significant at the implementation level. However, the regional consortia sought help in developing the networks by entering partnerships with some of the RBOCs. It gave the companies the opportunity to develop equipment for this kind of network, experiment with a new potential market, and develop closer relationships with universities. This process has continued and is widely publicized. The involvement of industry was not reduced to networking technologies, though this has been the aspect that gained most public attention. The use of supercomputers in corporate research for product development was a significant component of these partnerships as well (Mandelbaum & Mandelbaum, 1992).

## CONCLUSION

At the turn of the decade, the Internet was used widely in universities, government agencies, and many private corporations and was beginning to capture the attention and imagination of many people outside these circles. Computer networking was identified as the most prominent component of the High Performance Computing and Communications (HPCC) program, in spite of the fact that it counted for only about a fifth of the funds that were requested for it (U.S. Executive. OSTP, 1987). The NREN became the vehicle for discussion of the information infrastructure of the future. A multitude of sectors and interest groups tried to link their futures with the development of the network. The process continues, and gradually the role of the day-to-day workings of science and its institutions has moved to the background, but not without changing in the process. An indication of the new position of computer science, for example, is given in the first document that launched the almost $2 billion HPCC program released at the end of 1987. The letter of the Science Adviser to the President presenting the document states that "Another theme has come out of this report: within four decades, the field of computer science has moved from a service discipline to a pervasive technology with a rigorous scientific basis. Computer science has become important to our national security and to our industrial productivity" (U.S. Executive. OSTP, 1987). The world had been transformed as computer science came of age as a science.

Today's discussions of a national information infrastructure still owe many of their features to its previous background. A few observations will serve to illustrate this point and show some of the consequences it has for future deliberations on information infrastructure. First, computer networks are said to facilitate or lead to the formation of a variety of new social arrangements. The interpretation of experiences with the connections between groups and institutions during the formative period are invoked

to support these assertions. For example, academic computer networks were interpreted to have created a new environment for doing science in which researchers became more productive. They have also been interpreted to create coordination between research institutions and agencies or to facilitate partnerships between government, industry, and university. Recent reports often highlight their potential for community creation and for enhanced participation of citizens in the political process.

Networks are powerful metaphors for social relations. In combination with computers, which as Woolgar and Grint observed are evocative objects, they have reached mythic proportions (1991, p. 375). The network builders did in fact make use of the metaphorical value of networks that connect people and things during their implementation. Further, the flexibility in interpretation of the networks made it difficult, at times, to specify what objects were actually referred to, as in the case of the NREN component of the HPCC program, for example (Kahin, 1992, p. 6). In Woolgar and Grint's words, "The nature and capacity of the technology remain essentially indeterminate" (Woolgar & Grint, 1991, p. 370).

It seems to be the case that the very success of these networking efforts depended on the explicit use of the flexibility in possible interpretations of the nature and capacity of the technology. The protocols, which were identified as the heart of networking technology, were widely adopted because of their ability to remain flexible and allow many different groups to suit their changing needs within the framework they provided. The interpretive flexibility of the protocols is something that is put forward and highlighted rather than progressively eliminated to make the result irreversible. Further, rather than constructing a technology/society divide, the rhetorical strategies associated with the extension and stabilization of computer networks seemed to be associated with deliberate efforts toward blurring those boundaries by emphasizing the blending of social relations into the networked environment.

This feature of the networking process accounted for in this article points to an important characteristic of information technologies. The social relations in which any technology or set of technologies is embedded in all stages of its existence are crucial for understanding its very ontological status. In the case of information technologies, the correlation between the social networks, organizational arrangements, and institutional patterns in which they emerged, and continue to exist, and the shape and features of the technological ensembles are particularly clear. The architecture of computer networks, the conception of applications that facilitate various forms of interaction and communication, and the distribution of processing power and intelligence on the networks are part of processes that reach into deep recesses of the social fabric in which they exist. For that reason, the attribution of causality and impact of these technologies is very difficult. On the one hand, it is claimed that the network is the expression of various visions: elitism, democracy, education, entertainment (Hart et al., 1992). On the other hand, it is said that the technologies create new social arrangements (Rheingold, 1993). Of course, in general, both claims have elements of truth but both are insufficient as explanations. The process of coevolution of these social forms, which includes the technologies, must be tracked and accounted for in order to understand their status at any particular point.

This observation is very important for the study of the development of computer networking. The impetus for extending computer networks has several sources that in the aggregate have the effect of constituting computerization movements (Iacono & Kling, 1996).[3] However, even against the same background phenomena, they could have developed in ways other than they actually did, with different architectures embedded in other sets of social relations and institutional patterns. For example, contemporary global networks are not larger relatives of IBM's VNET, based on SNA protocols. Nor are they relatives of DECNET via MFENET, a possibility that was actually considered. They are not further elaborations and extensions of X.25 computer communications protocols. And even as they are based on TCP/IP, the further specification of functions of this protocol suite and their implementation were products and factors in the particular sets of relations and events we described earlier. Many important constraints and opportunities for the future evolution of the information infrastructure depend on how this process actually unfolded. At the same time, the patterns of interaction and structure of the social groups, organizations, and institutions involved, and the actual roles they play at various levels of networking development, are crucial factors in shaping the resulting infrastructural arrangement.

The role of NSFNET in the development of the Internet shows that information technologies are very significant in contemporary institutionalization processes. They embody social relations and contribute to stabilize routines and patterns. On the one hand, this speaks to the nature of information technologies, as described already. On the other, it cautions against careless use of a common distinction in the analysis of organizational environments between technical and institutional environments (Scott & Meyer, 1983). The creation of the computer networks was not driven chiefly by technical efficiency considerations but for participating organizations "to receive support and legitimacy from the environment" (Scott & Meyer, 1983, p. 140). In some instances, the widespread belief in computers as a means of improving the quality of life may play a role in encouraging these developments. However, the development of NSFNET as a link in the development of the Internet is not adequately accounted for as

computerization at any cost. Our analysis shows that a process of institutionalization and legitimation in science was achived in part by creating and embedding information technologies in a set of social relations. The result was a new sociotechnical ensemble with many features of its own.

A second observation, which is a consequence of the first, is that this process affects the way the position of users of computer networks is understood. The often repeated claim is that the expansion of the Internet is user-driven, and this is interpreted to have profound consequences for the organization of social communications. The relevant experiences were the community that developed and used the ARPANET, the exponential growth in NSFNET traffic beginning in mid-1987, the growth of UUCP/USENET and bulletin boards, and the fact that much of the traffic was of an informal or personal nature. However, it must be noted that the computer scientists who built and worked with ARPANET as well as the academic computer scientists who implemented the CSNET project were both users and designers or builders of the network. In the next stage, when NSFNET was planned and implemented, the computational scientists were also part of the project. They were not builders or designers in the same sense as the computer scientists were, but they certainly had more input into the shape of the network than a telephone service subscriber has on the telephone network. The relations between scientists and administrators on campus with respect to local network planning also illustrates this point.

The distinction between a category of users and another of designers or service providers is closely related to the technology/society divide. When this boundary is established, the designers and the users stand on opposite sides. The user-driven definition and growth of the networks are directly connected to the strategy of not constructing an impermeable boundary between technology and society. However, given that the network building process came about as a result of the negotiations between fairly autonomous groups rather than top-down management, it gave most participants a sense of being users giving input rather than either designers in charge or helpless users.

Third, another feature related to the blurred builder/user boundary often pointed out as a characteristic of this network is that it functions with no overall management. This is sometimes interpreted to mean that it has an inherently democratizing nature. This impression is connected to the fact that the architecture of the NSFNET was closely correlated with the relations between groups and organizations that developed it, of which the network was the visible expression. The "three-tiered" architecture allowed interconnection of consortia, agency, and corporate networks without surrendering jurisdictional boundaries. Many computer networks that were owned by government agencies, private corporations, or public carriers did exist, and many were created when the discussions of a national science network began. But it was their failure to transcend the boundaries of these jurisdictions that motivated the creation of the NSFNET and brought about the negotiations that "solidified" into the national network (Latour, 1991). In particular, the heritage of the ARPANET in the great expansion of networking into today's Internet must be understood in this light. On the one hand, it is true that computer networking technology has its origins in the ARPANET and that many of the networking experts who worked on the NSFNET and associated networks developed their skills working on the ARPANET. However, on the other hand, it was the failed attempt at direct ARPANET expansion beyond its jurisdiction that led to the implementation of NSFNET. Other agencies had similar problems with their networks. DOE challenged NSF's leadership in networking for many years, in part because it was reluctant to give up control of its resources and rely on others for its security. IBM's VNET was not completely accessible from the rest of the Internet for many years, even though IBM had been involved in the implementation of the NSFNET backbone since 1988.

The surprise may be that anything resembling an overall infrastructure could operate at all without, if not central management, at least a well-defined organizational structure like the electric utility or the telephone system. However, management has been a central issue all along with all the networks implemented in relation to NSF and the academic sector, and more and better management has always been demanded. On the one hand, it must be recognized that the period of rapid growth and interconnection of new networks to the NSFNET backbone was under the managerial oversight of the director of NSF's Division of Networking and Communication Research and Infrastructure, Steve Wolff. He played a key role in maintaining the necessary working relationships with all the parts involved to compensate for the lack of an overall formal structure. On the other hand, the point of lack of management is being made precisely to exploit the permeability of the technology/society boundary. With the involvement of new players, such as the telecommunications industry and the entertainment industry, which would like to create a more formal structure in order to offer services for profit, libertarian groups such as the Electronic Frontier Foundation are taking advantage of the situation created by the strategies of the academic sector in its implementation in order to stop a new boundary from being created. The strength of this position lies in the fact that the academic networking effort applied the "enlightenment" role of science to its project. The educational value of the network was suggested to be a direct result of the implementation of the new environment for science, just as one of the fruits of scientific research is supposed to be the education of the public by making its knowledge available to society. The

libertarian strategy is then to keep the policy outcome true to this original background discourse. The result of this process is still uncertain.

An important consequence of the implementation of the academic computer networks of the 1980s was the de facto adoption of TCP/IP as a standard protocol for computer communications beyond the academic sector. Besides the issue of the success of this particular networking technology, the significance of this fact is that a widely accepted standard was in fact put in place. As Busch and Tanaka pointed out in a recent article, the process of standardization is what creates the capitalist market (1996, p. 21). They referred to standardization of commodities that allows low transaction costs and the measurements necessary for economics to systematize their exchange. A computer communications protocol operates at a different level than a commodity standard. Rather than specify the characteristics of a single good that may be exchanged globally, it establishes the actual global marketplace for a broad range of goods and services to be delivered in electronic form. Attempts to create these conditions had been going on for more than a decade by the end of the period covered by this study but were unsuccessful. There are still many aspects of a full-blown electronic marketplace that have not been settled. However, the implementation of the academic networks and their extension to the entire economy has created conditions that earlier were only the subject of speculation (Dordick et al., 1981). The "negotiation, persuasion, and coercion that go into the production and reproduction of standards" had not been able to create one (Busch & Tanaka, 1996, p. 21). This case illustrates how science, technology, and society are built simultaneously or coproduced (Callon & Latour, 1981; Callon, 1991; Latour, 1983, 1987, 1991). The construction of computer networks effectively crossed the boundaries between science and society, and the new environment for science was built by rearranging the social order in the process.

## NOTES

1. The phrase is reproduced here in the plural to extend the notion proposed by Latour to multiple groups and objects.

2. In explaining the role of the academic sector in the development of computer networks, I use the concepts of institution, institutionalization, and legitimation as they are developed in social science accounts of organization rather than economics or political science (Powell & DiMaggio, 1991). In this perspective, institutions are social relations and patterns of interaction that have a degree of stability and are largely taken for granted by social actors. Legitimation has to do with "explaining or justifying the social order in such a way as to make institutional arrangements subjectively plausible" (Wuthnow et al., 1984, p. 50).

3. The description of the computer networking movement offered by Iacono and Kling (1996) with its organizations and recruitment mechanisms largely refers to recent phenomena, mostly occurring in the 1990s. Organizations such as FARNET (Federation of Academic Research Networks) and ISOC (The Internet Society) that are now enthusiastic proponents of a new future in cyberspace played more specific and circumscribed roles when they were created during the period accounted for in this article. FARNET initially represented the interests of regional consortia before NSF, the federal government, and ISOC took over the engineering and architecture roles of the boards and commitees that operated initially within the ARPANET framework. The fact that a broadly based computer networking movement emerged that has completely transcended the academic world and is partly supported by these organizations is in part a result of what this article maintains: The scientific community rearranged the social order through networking in the process of reconfiguring itself.

4. This is not meant to be an exhaustive list of events. It contains only the main ones mentioned in this article along with several of the better-known ones related to the ARPANET for reference.

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## APPENDIX I: ACRONYMS

| | |
|---|---|
| BITNET: | Because It's Time Network |
| CSNET: | Computer Science Network |
| CU4C: | Consortium of Universities Concerned about Campus Computing |
| DARPA: | Defense Advanced Research Projects Agency |
| DCA: | Defense Communications Agency |
| DOE: | Department of Energy |
| DOD: | Department of Defense |
| EARN: | European Academic Research Network |
| EDUCOM: | Interuniversity Communications Council |
| FCCSET: | Federal Coordinating Council on Science, Engineering, and Technology |
| ISO/OSI: | International Standards Organization/ Open Systems Interconnection |
| MFENET: | Magnetic Fusion Energy Network |
| MILNET: | Military Network |
| NASA: | National Aerospace Administration |
| NCAR: | National Center for Atmospheric Research |
| NREN: | National Research and Education Network |
| NSF: | National Science Foundation |
| NYSERNET: | New York State Education and Research Network |

| | |
|---|---|
| OMB: | Office of Management and Budget |
| OSTP: | Office of Science and Technology Policy |
| OASC: | Office of Advanced Scientific Computing at NSF |
| RBOC: | Regional Bell Operating Company |
| SPAN: | Space Physics Network |
| SURA: | Southeastern Universities Research Association |

## APPENDIX II: A TIME LINE[4]

**1966:** EDUCOM summer session on networking for science in Colorado.

**1968:** NSF's Office of Computing Activities establishes regional centers program.

**1969:** First ARPANET IMP installed at UCLA.

**1972:** NSF's Office of Computing Activities begins support for networking research. EDUCOM/NSF Workshop on national science networks. Demonstration of ARPANET at ICCC conference.

**1977:** EDUNET implemented as a network facilitator.

**1979:** First CSNET meeting at the University of Wisconsin organized by L. Landweber.

**1981:** First link established in BITNET between CUNY and Yale.
"Press Report" on the need for supercomputers in academic research.
CSNET contract awarded by NSF.
First of the international meetings ("Landweber meetings") organized by P. Kirstein.

**1982:** Report by the Lax panel on Large Scale Computing.

**1983:** Bardon/Curtis Report on the National Computing Environment for Academic Research.
MILNET split off ARPANET.
TCP/IP replaces NCP as the operating protocol.
U.S. House holds two hearings on supercomputing and research.
Landweber–Kahn agreement on mixed traffic on ARPANET links to CSNET.

**1984:** NSF establishes the Office of Advanced Scientific Computing headed by John Connolly.
First foreign node on CSNET connected in Israel.

**1985:** NSF awards grants for supercomputer centers.
NCAR meeting of supercomputer center directors: NSFNET architecture established.
Congressional hearings on federal supercomputer programs: first articulation of computer networking for science as information highways.

**1986:** First NSFNET backbone in operation.
Study on a National Research Network commissioned by an Al Gore amendment to NSF FY87 budget authorization; information superhighway metaphor is launched.

**1987:** OSTP report "A Research and Development Strategy for High Performance Computing" signals the direction toward NREN.

**1988:** New NSFNET backbone implemented by Merit, IBM, and MCI.
Gore-sponsored Congressional hearings on national networking begin.
ARPANET is retired.